Strategic use of stream stage recorders as proxy rain gauges in complex terrain

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Abstract

Precipitation measurements in complex terrain are notoriously difficult to obtain, particularly during cases of convective, thunderstorm precipitation or of mixed rain and snow. In such cases, stream stage and timing alone can provide useful proxy information for precipitation. Here, we use case studies from the Sierra Nevada, California to illustrate how small, self-recording pressure sensors can be monitor spatial patterns of precipitation in complex terrain.

I. Introduction

Precipitation varies markedly in regions of complex terrain, and standard precipitation gages, due to undercatch and siting logistics [e.g., *Sieck et al*., 2007], are often unrepresentative of regional rain rates and distributions. Radar views are blocked by complex terrain, and rain gages are generally sparsely distributed and concentrated at lower elevations. Thus, convective precipitation over high peaks may be entirely missed by conventional monitoring techniques.

Fortunately, distributed stream level recorders can be used to gain insight into spatial patterns of precipitation. Stream stage usually increases monotonically with increasing discharge. Thus, while stage information cannot reveal the precise quantity of water moving down a given stream, it can be used to identify the timing of peak and minimum flows, and the times when flow volumes are increasing and decreasing. This timing alone can identify where and when precipitation has occurred, and is particularly useful in cases of convective precipitation and mixed rain and snow events, as detailed below.

II. Summer thunderstorms

As snowmelt becomes a less reliable source of water in late summer, summer precipitation will become increasingly important in controlling late summer soil moisture and minimum flows in mountain streams, both of which are crucial to ecology and summer water supplies. Focusing on the western United States, *Hamlet et al.* [2007a; 2007b] found that modeled late-season soil moisture depends more on summer precipitation than on temperature or the spring snowpack. Thus, understanding and predicting summer precipitation, which most often falls during thunderstorms at high elevations, is important to predict drought severity in these regions.

Figures 1 and 2 illustrate the difficulty of monitoring summer thunderstorms with existing precipitation gage networks. On the afternoon of 23 July 2003, water levels rose to over 7 times their morning depth in several headwater streams of the Merced River, Yosemite National Park, California (Figures 1a and 2). At the same time, no increases in streamflow were observed in the Tuolumne River drainage to the north (Figure 1b and 2), and a trace amount of precipitation (< 1 mm) was recorded in only one of the fifteen operating rain gages located nearby (Figures 1c and 2). On 24 July, only one precipitation sensor recorded precipitation (9 mm) and only one stream gage recorded a water level rise. On 26 July, precipitation (ranging from 1 to 4 mm) was recorded in 4 rain gages, but no stream experienced a rise in water level.

Such complicated patterns were observed throughout the summer thunderstorm season. Distributed stream stage recorders could monitor the frequency and spatial distribution of summer thunderstorms more effectively than traditional precipitation gages. In such applications small basins serve as the “rain catch domain” and are more representative of total precipitation than point gauges. These measurements could be combined with lightning strike records to pinpoint thunderstorm locations (Orville 2008).

III. Rain vs. Snow

Distributed stream sensor networks can also help identify regions receiving rain vs. snow. For a given storm, one of the greatest difficulties in flood prediction in complex terrain involves determining which percentage of a river basin receives precipitation as rain (rapid runoff) and which percentage receives precipitation as snow (delayed runoff). Standard precipitation gages and snow sensors have difficulty distinguishing between solid and liquid precipitation, such that only direct observations [*U.S. Army Corps of Engineers*, 1956], optical disdrometers [*Yuter et al.*, 2006], or co-located snow pillow, snow depth, and heated precipitation sensors [*Lundquist et al.*, 2008] can identify precipitation type. All of these options are expensive and are only representative of precipitation at a point.

Distinguishing rain from snow is particularly important in maritime basins spanning a wide range of elevations, such as the North Fork American River basin in the Sierra Nevada, California. Pressure sensors were deployed in four subbasins of the North Fork American River, selected such that each drains a narrow range of elevations (Figure 3). Thus, their varying responses to different storms provide a measure of where rain contributes to runoff during each storm and where snowmelt contributes runoff in the spring, providing an independent measure of where and when precipitation contributes to runoff (Figure 4).

Water year 2006 was characterized by a series of warm, high rainfall storms in late-December/early-January, and a series of much colder storms in March and April (Figure 4a). The December 2005-January 2006 storms were characterized by high melting levels, and all three subbasins, at altitudes of approximately 500 m, 1500 m, and 2000 m, contributed to runoff (Figure 4b). In contrast, in March and April, Onion Creek, the highest subbasin, did not contribute directly to discharge, but rather accumulated snow, which melted and contributed to runoff in May and June (Figure 4b).

In addition to identifying the different source areas for the total basin discharge, the monitored subbasins illustrate how basin transport times vary between storms and locations. In the early season (Figure 4c), increases in the main NF discharge lagged behind increases in the small subbasins by about 8 hours for the first four storms in the sequence and experienced only a 1 hour lag in the fifth storm, the New Year's flood. By the spring (Figure 4d), the lag was less then 3 hours for all storms.

IV. Conclusions

These examples illustrate how stream stage can provide surrogate precipitation measurements in complex terrain. These sensors can deployed quickly and inexpensively and can provide an independent check, and perhaps even input, for distributed hydrologic models, which are often crippled by a lack of quality precipitation driving data in complex terrain. Detailed instructions of how to deploy stream stage recorders are included in an electronic supplement to this article.

V. Acknowledgements

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VII. Figure Captions

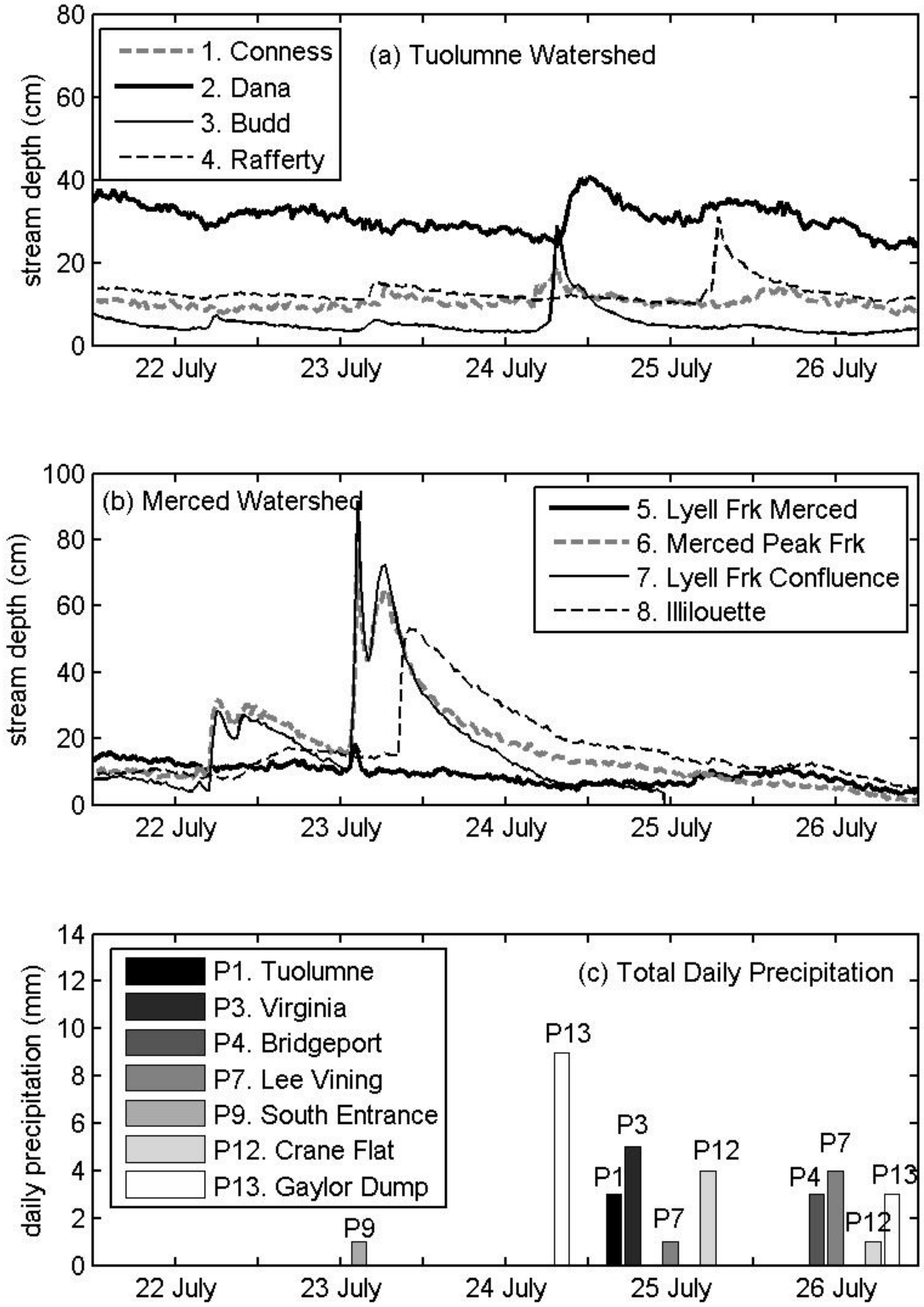
Figure 1 Stream level records from (a) four subbasins of the Tuolumne River, and (b) four subbasins of the Merced River for 22 to 26 July 2003. Note: Axis date labels are centered at 12:00 noon local time, with unlabeled tick marks representing midnight. (c) Daily precipitation records from 7 of 15 precipitation sensors near the basins. The 8 sensors not listed in the legend all reported no precipitation throughout the shown period. Locations of all gages are labeled by numbers on Figure 2.

Figure 2 Location of thunderstorm on 23 July 2003, as indicated by the horizontally-striped subbasins and the arrow. Dashed outlines identify monitored subbasins of the Tuolumne (northern) and Merced (southern) Rivers in Yosemite National Park, California. Striped subbasins reported stage rises up to 7 times higher than the prior flow level, indicating substantial precipitation (Figure 1b). With the exception of a trace amount less than 1 mm at the Southern Park Entrance (marked P9, near the lower left-hand legend), no gages recorded precipitation on 23 July. 15 operating precipitation gages are marked by P and a symbol representing the operating organization. Snow pillow sites without P are able to measure solid, but not liquid precipitation. Note: P4, the Bridgeport precipitation gauge, is located just north of the mapped area.

Figure 3 Fraction of basin area below each elevation for the entire North Fork American basin and 4 monitored subbasins. (Note: The Blue Canyon stream record is not shown in Figure 4 because the instrument and its anchor were moved out of the stream during a December flood.)

Figure 4 Water year 2005-2006: (a) discharge at the North Fork stream gage, (b) stream stage at three subbasins at different elevations, (c) zoomed view of late December/early-January, with discharge (thin black line) plotted on left axis and stage on right axis, and (d) same as c, but zoomed to March-April.

Figures



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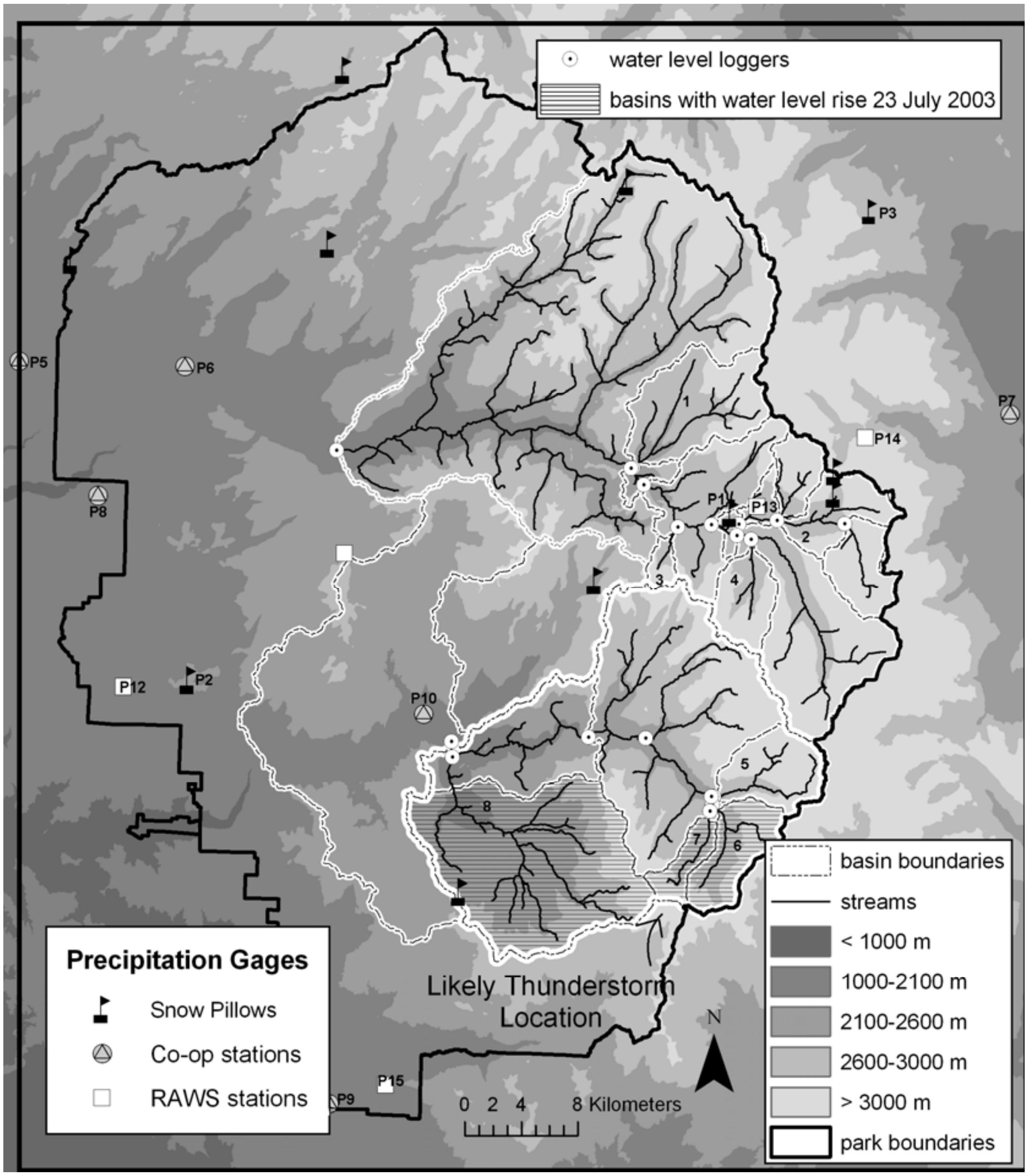

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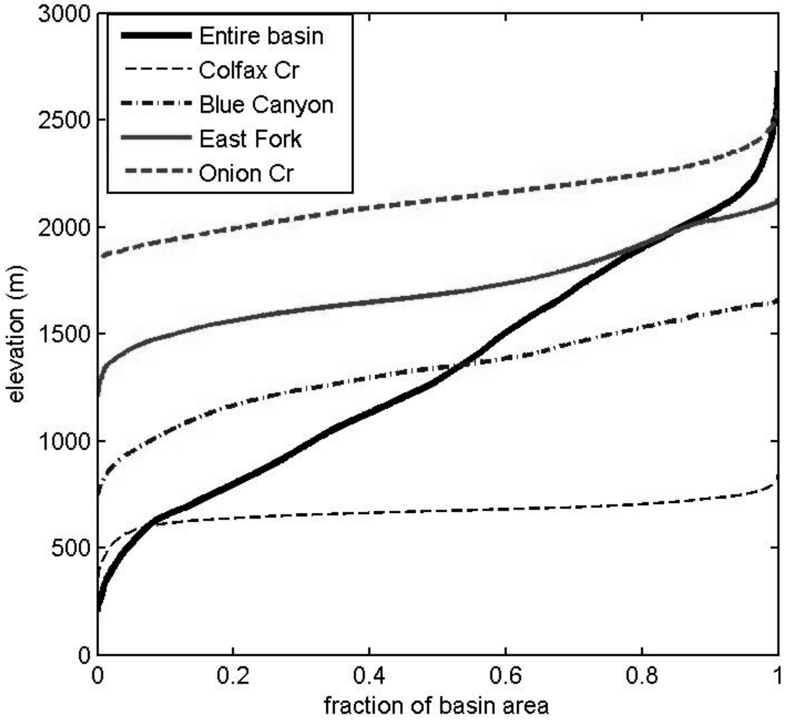

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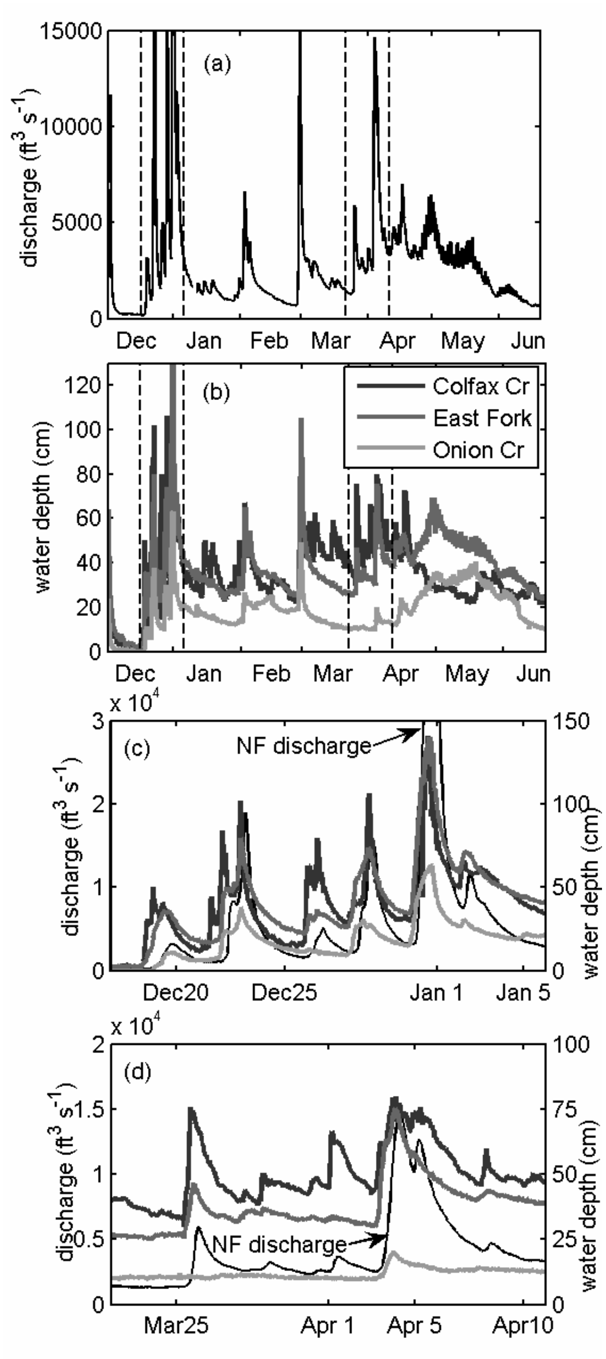

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